INTERACTING PHOTONS

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We investigate optical systems where nonlinearity, noise, memory effects, and dissipation can synergistically enhance the transport of energy and information in light. We are mainly interested in fundamental physics questions with technological relevance, such as: What is the optimal strategy for detecting a weak optical signal in a noisy environment? What are the fundamental limits to the energy efficiency, speed, and precision of optical devices? To address these and related questions, we develop and test new ideas that draw inspiration from recent trends in photonics, nonlinear & statistical physics, quantum science, condensed matter physics, thermodynamics, materials science, information theory, and complexity science.

Highlights

- We discovered a universal scaling law for the dynamic hysteresis of systems with memory.
- We demonstrated how memory effects can make stochastic resonance (noise-assisted signal amplification) extremely broadband.
- We introduced nonlinear optical sensing strategies with surprising advantages over linear strategies. Examples of such advantages include noise-enhanced sensitivity, and overcoming the trade-off between measurement speed and precision.
- The first PhD student of the group, Dr. Zhoumuyan Geng, obtained his PhD from the University of Amsterdam in 2022.

Plans

Consider an optical device processing information, like a switch or a sensor. What are the fundamental limits to its energy efficiency, speed, and precision, in the inevitable presence of noise? Surprisingly, there is currently no way to answer that question which is vital to the future of many optical technologies. One of our main goals for the coming years is to develop the methods necessary to answer that question. To achieve that, we will combine ideas from information theory, thermodynamics, and optics, in order treat optical devices as information processing machines subject to thermodynamic constraints. We envision optical experiments that will test our ability to treat laser-driven resonators as optical engines, and to use the framework of information thermodynamics to optimize their performance in information-processing operations.

Key research items

1. K.J.H. Peters, J. Busink, P. Ackermans, K.G. Cognée and S.R.K. Rodriguez, *Scalar potentials for light in a cavity*, Phys. Rev. Res. 5, 013154 (2023)
2. K.J.H. Peters and S.R.K. Rodriguez, *Exceptional precision of a nonlinear optical sensor at a square-root singularity*, Phys. Rev. Lett. 129, 013901 (2022)
3. B. Garbin, A. Giraldo, K.J.H. Peters, N.G.R. Broderick, A. Spakman, F. Raineri, A. Levenson, S.R.K. Rodriguez, B. Krauskopf and A. Yacomotti, *Spontaneous symmetry breaking in a coherently driven nanophotonic Bose-Hubbard dimer*, Phys. Rev. Lett. 128, 053901 (2022)
4. K.J.H. Peters, Z. Geng, A.A.P. Trichet, K. Malmir, J.M. Smith and S.R.K. Rodriguez, *Extremely broadband stochastic resonance of light and enhanced energy harvesting enabled by memory effects in the nonlinear response*, Phys. Rev. Lett. 126, 213901 (2021)
5. Z. Geng, K.J.H. Peters, A.A.P. Trichet, K. Malmir, R. Kolkowski, J.M. Smith and S.R.K. Rodriguez, *Universal scaling in the dynamic hysteresis, and Non-Markovian dynamics, of a tunable optical cavity*, Phys. Rev. Lett. 124, 153603 (2020)

A laser-driven oil-filled cavity has memory in its nonlinear optical response. The future state of the system depends not only on the present, but on its entire past. Using this system, we discovered a universal scaling law [5], and an extremely enhanced bandwidth for noise-assisted signal amplification [4].